days that occurred when the pressure was above 30.05 inches at Seattle came when the vapor pressure was above 0.34 inch at Roseburg, and the Roseburg pressure was from 0.02 to 0.10 inch lower than at Baker (fig. 5). In fact, when such a situation prevails, the probability is strongly in favor of dangerous storms over the area under consideration. During the same month, when the pressure is below 30.05 inches at Seattle, vapor pressure above 0.35 inch at Roseburg, and the pressure at Roseburg not more than 0.12 inch higher than Baker, the lightning fire hazard is great. There was a total of 53 cases during the August months when the pressure was below 30.05 inches at Seattle, but did not meet the other requirements, and only four "scattered" and no "wide-spread" storm days occurred (fig. 6).

METEOROLOGICAL CONDITIONS IN MORNING AND THUNDERSTORM ACTIVITY NEXT DAY

Studies of the same character as the foregoing were made to find relationships between meteorological elements observed at 8 a. m. E. S. T. and the occurrence of thunderstorms the following day.

The relationships described hereunder for July are intended for consideration in connection with the weather maps from June 30 to July 31, inclusive.

It was found that during July when the pressure is higher than 30.02 inches at Seattle and the pressure is higher at Roseburg than at Baker conditions are relatively safe (fig. 7). Out of a total of 98 observations no "wide-spread" and only two "scattered" storm days occurred under these conditions. There is no well defined correlation between these factors and the occurrence of thunderstorms during August.

During July conditions are relatively dangerous (thunderstorms occurring in about 50 percent of the cases) when the morning pressure at Seattle is below 30.04 inches and not more than 0.12 inch higher than at Kamloops, and in addition the pressure at Seattle is higher than at Roseburg or not more than 0.04 inch lower. On the other hand relatively safe conditions prevail when the pressure at Seattle is below 30.04 inches and the other observations do not come within the above classification. Out of a total of 41 such cases, there were 2 "wide-spread" and 1 "scattered" storm day (fig. 8).

During the same month, thunderstorms occurred in about 50 percent of the cases when the pressure at Seattle was above 30.02 inches and higher than at Roseburg, and in addition the Seattle pressure was not more than 0.08 inch higher than at Kamloops. Only 1 "wide-spread" and 3 "scattered" storm days occurred out of the 119 days when the pressure at Seattle was above 30.02 inches, and the other observations did not come within the above classification (fig. 9).

During August conditions are relatively safe when the pressure at Seattle is below 30.04 inches and more than 0.14 inch higher than at Kamloops, or if the Seattle pressure is either higher or not more than 0.04 inch lower than at Roseburg (fig. 10). Forty-five cases came within this classification and only one "wide-spread" and no "scattered" storm days occurred. With pressure higher than 30.02 inches at Seattle and more than 0.20 inch higher than at Kamloops, conditions are relatively safe (fig. 11). One "wide-spread" and one "scattered" storm day occurred under these circumstances out of a total of 35 observations.

There were no "wide-spread" or "scattered" storm days during July out of 57 cases with pressure at Seattle above 30.02 inches and the pressure at Seattle the same or lower than at Roseburg (fig. 12). Under these conditions during August, 1 "wide-spread" and 3 "scattered" storm days occurred out of 47 cases.

CONCLUSION

It is regretted that the record available for study is short and the conclusions, as mentioned above, must not be considered as final. However, it is believed that there are sufficient data to justify development of working hypotheses at the present time.

LIGHTNING STORMS AND FIRES ON THE NATIONAL FORESTS OF OREGON AND WASHINGTON

By WILLIAM G. MORRIS

[Pacific Northwest Forest Experiment Station, Portland, Oreg. Summarized by W. R. Stevens, Weather Bureau, Washington]

Lightning causes more than one-half of all the fires on the national forests of Oregon and Washington, where an average of 750 fires annually is attributed to this one cause. These lightning-caused fires cost hundreds of thousands of dollars to extinguish; they destroy an enormous amount of timber, imperil entire watersheds by destroying the cover at the headwaters of important streams and wreak heavy damage in recreational areas of these two States.

Unlike man-caused fires, which are potentially preventable, lightning fires can never be prevented. For lightning fires, the forest protectionist has recourse only to prompt detection and suppression. A single storm may start so many fires that the protective forces are strained to the utmost to reach and extinguish every fire before any attains devastating size. Since, on most national forests of the region, many of the lightning fires are at considerable distances from the areas of everyday man-caused risk, special steps must be taken to protect the lightning fire zone whenever lightning storms are expected.

The study here reported on was made (1) to discover the fundamental characteristics of lightning storms andthe fires they start so as to assist in planning the best possible systems of lightning fire control, and (2) to supply some of the basic information needed for effective lightning storm forecasting.

BASIC DATA

This study is based on more than 6,000 systematic reports describing lightning storms seen by United States Forest Service fire lookouts in Oregon and Washington during the summer months from 1925 to 1931, inclusive. During this period an average of about 200 lookouts have submitted reports each year. Each report shows the following three points concerning the location and movement of an individual lightning storm: (1) Location of the storm and the time when it was first seen by the lookout; (2) location of the storm (and in many cases the time) when it was nearest the lookout; (3) location and time when the storm was last seen by the lookout. The territory for which these reports were made includes all of the Cascade Range from southern Oregon to the British Columbia boundary, the Coast Range in western

Oregon, the Blue Mountains in eastern Oregon and southeastern Washington, and the Okanogan Highlands in northeastern Washington. The total area covered by the study is approximately 25,000,000 acres. Although this is only about one-fourth the area of the two States, most of the lightning storms occur in these mountainous regions.

MAPPING THE REPORTS

The following method was used to analyze the lookout reports graphically. Storm reports for individual days were plotted on tracing paper laid over a State map showing the lookout stations (scale one-eighth inch to the mile). The report of each lookout, giving the location and time of occurrence of a lightning storm was plotted on the daily storm map. Many times, lookouts reported separate storms in progress simultaneously at different points on the horizon. Such plotted reports were treated as individual storms whenever the time and distance between them indicated that they were distinct storms. By graphically sorting all plotted reports and combining those for the same storm, the approximate center of each individual storm path was determined and drawn. The census, in this way, was based on the number of storms instead of either the number of people who saw the storms or the number of days when storms occurred.

From the plotted reports, it was plain that a single lightning storm in Oregon and Washington usually is not an isolated cumulo-nimbus cloud moving across the country in a narrow path like many storms in the Eastern States. Instead, it often covers the entire sky from the viewpoint of many lookouts. In several cases a lightning storm had a path 40 miles wide.

SUBREGIONS

Mapping of storm occurrence and movement had not progressed far before it became increasingly evident that there are three very distinct areas in the region, each of which is distinguished by peculiarities in the occurrence and behavior of lightning storms. One of these areas is the Blue Mountains in Oregon. A second very distinct subregion comprises the remaining national forests in western and central Oregon. The third area is the Cascade Range and Okanogan Highlands of Washington.

It was found that very few individual storms cross from one subregion to another and that extensive storms sometimes occur in one subregion on days when no storms occur in adjacent subregions.

CHARACTERISTICS OF LIGHTNING STORM OCCURRENCE

There was an average of 23 days per year in western and central Oregon, 25 days in Washington, and 27 days in the Blue Mountains when lightning storms occurred on or in the vicinity of the national forests between July 1 and September 10.

In spite of there being 63 days from 1925 to 1931 when "general" storms occurred somewhere in Oregon or Washington, there were only 4 days when the storms were "general" simultaneously in all subregions, and 13 days when they were "general" in two subregions at the same time. In 16 cases "intermediate" and "general" storms occurred simultaneously in 3 subregions, and in 38 cases they occurred at the same time in 2 subregions. During the 7-year period, "intermediate" or "general" storms developed somewhere in Oregon and Washington on 149 days.

Twenty-seven percent of the "general" days produced individual storms in the early morning (4 a. m. to 10 a. m.), and 28 percent produced storms at night (10 p. m. to 4 a. m.). In contrast, occurrence of storms on "local" days was restricted almost entirely to the period between 10 a. m. and 10 p. m.

In Washington, a greater proportion of the storm days than in other subregions produced storms at night, and in the Blue Mountains a greater proportion produced storms in the early morning.

TYPES OF STORM DAYS

While the daily storm maps were being made it became apparent that individual lightning storm days affecting each subregion could be sorted into three types according to the extent of the storms within the subregion.

The "general" type of lightning storm day either has many small storms which affect two-thirds or more of a subregion, or has one or more storms which make a continuous track at least two-thirds the length of the subregion. An average of 35 lightning fires per day started on "general" storm days from 1925 to 1931. One "general" lightning storm day on August 2, 1929, was responsible for 215 lightning fires in the national forests of Washington. Sixty-six percent of all lightning fires in the region are started on "general" days, although these days form only 16 percent of the total number of storm days. Every "general" storm day during the period resulted in lightning fires on the national forests.

The "local" type of lightning storm day has only one or a few storms affecting a small area of a subregion. On several "local" days the only storm which occurred was less than 15 miles long and 5 miles wide. Usually, the "local" storms were from 15 to 60 miles long and about 5 miles or more in width. When no more than 4 or 5 such storms occurred and they were restricted to 1 part of a subregion the day was classified as "local." An average of only one fire per day started on "local" days. These days accounted for 10 percent of the lightning fires, although they form 59 percent of the total number of lightning storm days.

An "intermediate" storm day is one on which the storms are more wide-spread than on the "local" day but less extensive than on the "general" day. The "intermediate" storm days were responsible for 24 percent of the lightning fires. An average of nine fires per day started on "intermediate" days.

During the period studied there were 86 "general" storm days, 135 "intermediate", and 307 "local" days.

The "general" storm days cause nearly all of the peak load of lightning fires in the national forests of Oregon and Washington. They yield a great number of fires, and the fires come all at once. There may be 30 lightning fires set within 2 or 3 hours on a single national forest. This sudden outbreak of fires taxes the forest protective forces to their physical limits. In contrast the "local" storm days cause no overload. The few fires started on "local" storm days usually can be reached before they spread greatly. If a forest supervisor knew definitely that an expected storm would be of the "local" type, it would not be necessary to make special preparations for lightning-fire suppression, but, if he expected a "general" storm day he would be justified in making extraordinary preparation to handle a peak load of lightning fires.

CHARACTERISTICS OF LIGHTNING-STORM BEHAVIOR

Most individual lightning storms on the national forests of Oregon and Washington affected an area 11 to 60 miles in length, or appeared to move through that distance. Only a few storms have exceeded 80 miles in length, yet one storm in Washington is definitely known to have been at least 280 miles long.

The speed of individual lightning storms in the region was usually from 6 to 20 miles per hour. Very few storms moved faster than 40 miles per hour.

Lightning-storm movement was most often toward some northerly direction. In the Blue Mountains many more storms move toward the northeast than any other direction. Between 10 and 20 percent move toward each of the following directions: North, east, and southeast. Less than 5 percent move toward any one direction between south and northwest, inclusive. In western and central Oregon the most frequent directions of movement are north and northeast, each direction having nearly an equal number. Nearly 20 percent of the storms in this section move toward the northwest. The Washington storms are even less consistent in their direction of movement. For example, 56 per cent of them are about evenly divided between north, northeast, and southeast and 35 percent between south, east, and northwest.

The uniform direction of movement in certain subregions may be of some aid in obtaining warning of storms already in progress. Forests in the Blue Mountains can expect about 80 percent of their lightning storms to approach from the southward, and look-outs can warn fire-control forces to the northward. An estimate of the hour when a storm will reach a certain locality can be obtained by plotting and timing its movement during the early part of its course. If a lightning storm is seen forming, there are 60 chances in 100 that it will move forward at least 20 miles before dissipating. If a storm is 15 miles distant when first observed, there are about 80 chances in 100 that it will not arrive within 45 minutes.

The percentage of lightning flashes which occur between one cloud and another has been considered an important characteristic which may distinguish fire-causing from non-fire-causing lightning storms. The observations made by United States Forest Service look-outs include the total number of lightning flashes seen and an estimate of the percentage of these flashes which were confined to the clouds.

The observations indicate that lightning storms in the mountains of Washington and Oregon are most frequently the type having a large percentage of cloud-to-cloud flashes. The percentage of look-out reports indicating various proportions of cloud-to-cloud flashes is as follows:

Cloud-to-cloud flashes (percent):	*Percentage of 4,800 observations*
0 to 25	24
26 to 50	18
51 to 75	18
76 to 100	40

The percentage of cloud-to-cloud flashes was greater when more than 10 flashes were seen than when less than 10 were observed by the lookout.

There is little difference between the percentages of cloud-to-cloud flashes in day and night lightning storms. Likewise, there is no significant difference between the percentages of cloud-to-cloud flashes in different years. "Local" storm days have a greater percentage of cloud-to cloud flashes than the "general" days. This may account partly for the greater number of lightning fires started on "general" storm days.

LIGHTNING STORM PATHS AND "BREEDING" SPOTS

It has been suggested many times that there may be lanes formed by valleys or ridges, which lightning storms follow consistently. A careful study of seven yearly composite maps of storm paths (fig. 1) shows that there are no such narrow routes of travel for storms in the national forests of Oregon and Washington.

The existence of lightning storm "breeding" spots has been mentioned by several writers and by many casual observers. These spots are conceived as being valleys, mountain peaks, etc., over which lightning storms form time after time. If such "breeding" spots exist, and if their locations were known, they could be watched closely in order to obtain advance warning of developing lightning storms. In order to locate any such "breeding" spots, starting points of the 2,600 individual storms reported during the 7 years were located on one map. This map indicated that such definite spots do not exist in the region studied.

Each series of consecutive storm days in a single subregion was studied to learn whether it is common for a certain type of storm day to be a forerunner of other storm days.

It was found that between July 1 and September 10, whenever there had been no "intermediate" or "general" storms for 2 or more days in the Blue Mountains, the occurrence of an "intermediate" storm day was followed in 46 percent of the cases by either another "intermediate" or a "general" storm day in that subregion. In Washington 39 percent and in western and central Oregon 42 percent of the "intermediate" storm days were followed by other "intermediate" or "general" storm days in those subregions.

LIGHTNING STORM ZONES

A map showing zones of relative lightning storm frequency was constructed from the daily charts of individual storm paths (fig. 2). A comparison of these zones with the topographic map suggests a close relationship between storm frequency, the mountains, and the hot summer climate east of the Cascade Range. The boundaries of lesser storm frequency conform especially well with the outlines of the foothills. The zones of greatest frequency are east of the Cascade Range in mountainous areas. The study shows that certain national forests have twice as many storms as those adjoining. Furthermore, certain parts of a forest may have twice as many storms as other parts of the same forest.

LIGHTNING FIRE KINDLING MATERIALS

A knowledge of the relative number of lightning fires ignited in each type of forest material is necessary in estimating lightning fire danger from the standpoint of inflammability of fuels. If the fuels which most frequently kindle lightning fires are very wet due to recent rains, the chance of ignition by a lightning strike will be small, but, if these fuels are dry, there is a great chance that lightning fires will be started.

The number of lightning fires ignited in each fuel material at each altitude on each national forest from 1925 to 1930, inclusive, was determined from the systematic Forest Service reports which describe the circumstances concerning every fire within the national forests. Needles and duff on the ground formed the most important kindling material. Live trees were second in importance and dead trees were third. In several national forests on the west slope of the Cascades, however, dead trees kindled more fires than any other material. Grass was important only in northeastern Washington.

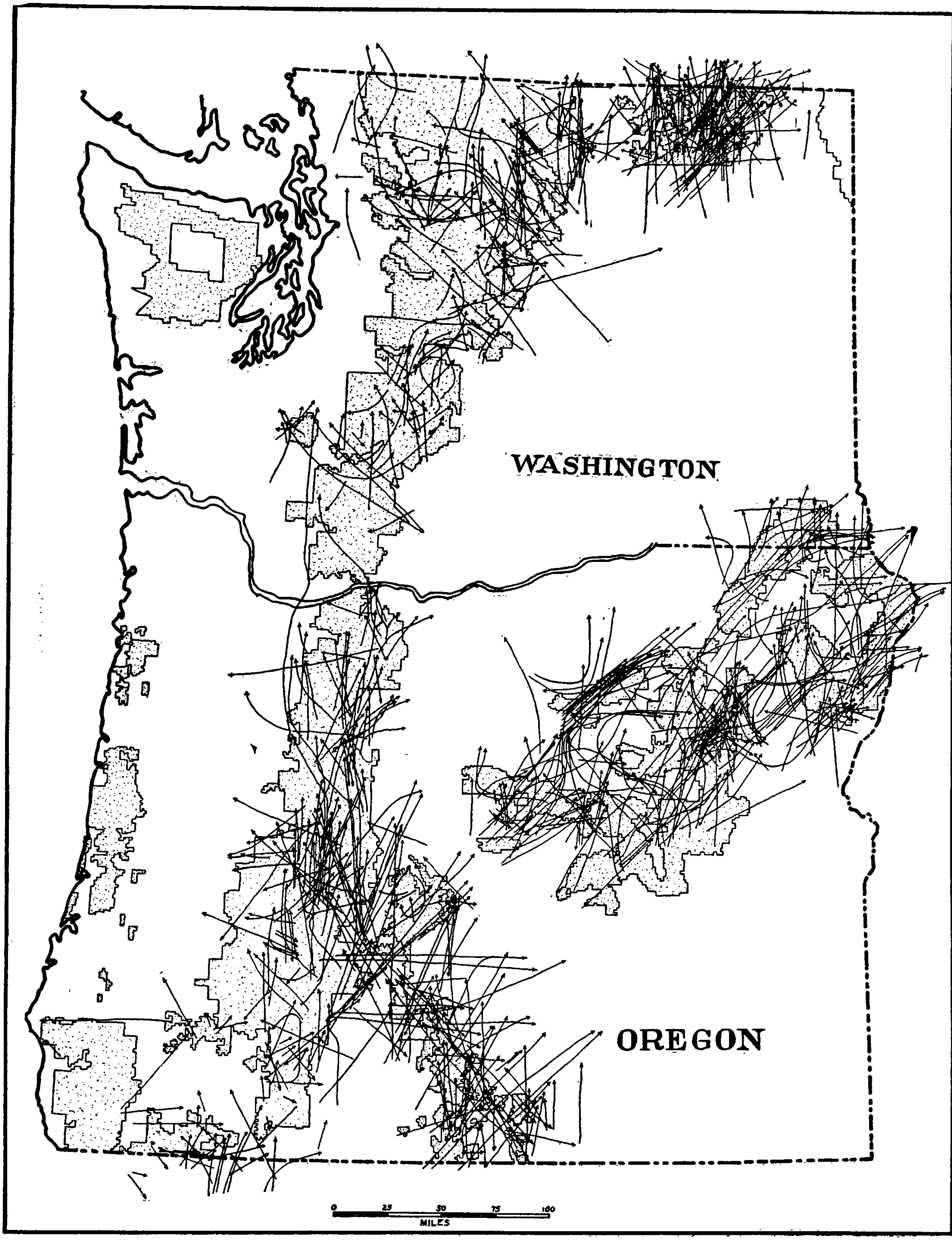

Figure 1.—Paths of all lightning storms reported by national forest fire lookouts in Oregon and Washington during 1930.

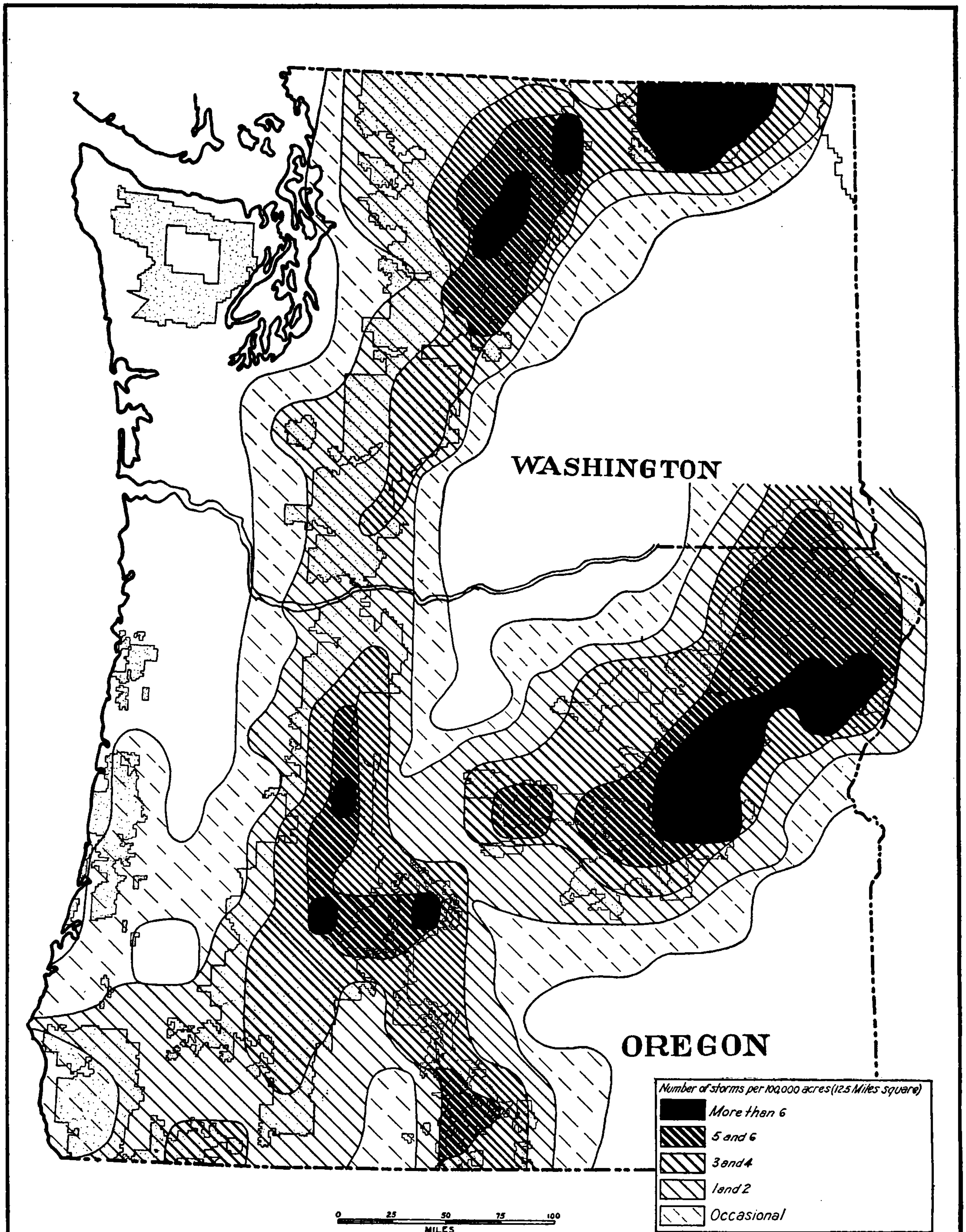

FIGURE 2.—Zones of average yearly lightning-storm distribution in the vicinity of the national forests of Oregon and Washington as determined by more than 2,600 storm paths charted from national forest fire lookout reports during the 7-year period, 1925-31, inclusive.

LIGHTNING FIRE FREQUENCY AT DIFFERENT ALTITUDES

It has been a common belief that zones of great lightning fire risk exist at high altitudes more frequently than at low altitudes because the highest mountains seem more exposed to lightning flashes; but analysis of the altitudinal distribution of lightning fires in the mountains of Oregon and Washington shows that on a given national forest the number of lightning fires per acre at low altitudes is as great as the number per acre at high altitudes if approximately the same number of lightning storms occur over the two areas and if there is sufficient kindling material. The greater number of lightning fires simply occur at the level containing the greater part of the land surface. To determine this relationship precisely, the area of forest land between 0 and 2,000 feet altitude, 2,000 and 4,000 feet, etc., was planimetered from United States Geological Survey topographic maps of three national forests in different parts of Oregon and Washington. (Complete topographic maps were not available for additional national forests having a sufficient number of lightning fires for analysis.) In each case, the number of lightning fires which have occurred at each altitude during a 6-year period was directly proportional to the area of forest land at each altitude.

LIGHTNING FIRE ZONES

An attempt was made to construct a map showing comparative horizontal zones of lightning fire frequency. The starting points for 5,500 lightning fires which occurred on the national forests of Oregon and Washington from 1925 to 1931 were plotted on a single map. At first there appeared to be a few fairly well-defined groupings of these fires, but further analysis showed that there are no zones of consistently repeated fire occurrence.

Detailed study of lightning fire maps for individual days indicates why there is little or no consistent zonation of lightning fire occurrence. Usually, the fires set on any 1 day are widely scattered throughout the area covered by the storms, which is often 7,500 square miles; but occasionally the storms of a single day set many fires within a small area, giving to that area the appearance of a dangerous fire zone. Several years often elapse before another fire is set in the same locality, even though storms occur over it.

THE EFFECT OF TIME OF OBSERVATION ON MEAN TEMPERATURE[1]

By W. F. RUMBAUGH

[Weather Bureau, Boise, Idaho, October 1934]

In meteorological records made at cooperative stations, the writer has frequently observed differences in mean temperature at adjacent stations which could not be satisfactorily explained by topographical influences, but the observations at these stations were taken at differing times of the day, so this investigation was pursued to determine what effect the *time of observation* has on the computed mean temperature. For the benefit of readers not familiar with the climatological work done by the Weather Bureau, it may be stated that mean monthly temperatures at all stations, whether regular Weather Bureau or cooperative, are computed from daily maximum and minimum temperatures for a definite 24-hour period ending at the same time each day for a particular station. At regular Weather Bureau stations, this period ends at midnight. As a midnight-to-midnight standard has been adopted for regular Weather Bureau stations, means obtained by using 24-hour periods ending at other times of the day were compared with those obtained by using the midnight-to-midnight basis.

Effort usually is made to have the observers at cooperative stations read their maximum and minimum thermometers at as near sunset as practicable. Comparable values would be obtained if all cooperative observers could be induced to take their readings at that hour. In numerous cases, however, it is impossible to obtain an observer who is willing to take the readings outside of regular business or office hours, especially if his employers require him to act as observer as a part of his work. These observers usually desire to take the readings either when they begin work, at about 8 a. m., or just before leaving, at about 5 p. m., in most cases. Practically all cooperative observers take their readings at one of the hours mentioned above, namely, sunset, 8 a. m., or 5 p. m. For this reason, means from extremes for 24-hour periods ending with these hours, together with the midnight standard adopted by the Weather Bureau for comparison with records made at regular Weather Bureau stations, are compared in this study.

In order to pursue this investigation, it was necessary to have four sets of thermometers in a ground shelter, and read each set at one of the times named above for a period of several years; or to obtain thermograph records made in a ground shelter for a like period of time. Records made in a roof shelter are not comparable with those made in a ground shelter, hence the use of regular station records was precluded. When, however, it was discovered that the United States Bureau of Entomology at Twin Falls had been making thermograph records in a ground shelter for a period of over 6 years, the second method was adopted, and the original record sheets here referred to borrowed in order to extract the necessary data.

Twin Falls is situated near the center of a large irrigated tract, surrounded by mostly level country. The nearest mountains are about 20 miles to the southeast. As there are no mountains nearer than 100 miles in the direction from which the prevailing winds blow, and none nearer than 20 miles in any direction, air-drainage and inversion effects are largely eliminated. The climatic conditions are representative of a large part of the intermountain region. There usually is little wind during the night and early morning, especially if the sky is clear, but frequently considerable air movement during the warmer part of the day.

In the intermountain region, the maximum temperature occurs much later in the afternoon than in the moister regions of the country. At Twin Falls, it usually occurs between 4 and 6 p. m. from March through September, and only about an hour earlier during the other months,

[1] This study of the effect of time of observation on the *mean* monthly temperature as determined from the daily maxima and minima may be compared with the investigation by E. S. Nichols, of the effect of time of observation on the minima and maxima themselves, MONTHLY WEATHER REVIEW, September 1934. The primary question considered in these papers is that of the *comparability* of records; on the closely related problem of the discrepancy between temperature means as determined by different conventional observing procedures and the true mathematical mean, reference may be made to: Hartzell, Comparison of Methods for Computing Daily Mean Temperatures, MONTHLY WEATHER REVIEW, November 1919; McAdie, Mean Temperatures and their Corrections in the United States, Washington, 1891; Hann, Lehrbuch der Meteorologie, 4 aufl., pp. 93-96.—EDITOR.